

Grant

IN-04-112

143093

14

**SEMI-ANNUAL PROGRESS REPORT**

**NASA GRANT NAG 1 1423**

**GPS INTERFEROMETRY**

**April 1 - September 30, 1992**

by:

**Frank van Graas, Ph.D.  
Principal Investigator**

**Prepared for:**

**NASA Langley Research Center  
Hampton, VA 23665**

(NASA-CR-192301) GPS  
INTERFEROMETRY Semiannual Progress  
Report, 1 Apr. - 30 Sep. 1992  
(Ohio Univ.) 14 p

N93-18873

Unclass

G3/04 0148093

## TABLE OF CONTENTS

1.	SUMMARY .....	3
2.	INTRODUCTION .....	3
3.	SYSTEM ARCHITECTURE .....	4
3.1	Ground Sub-System (GS) Architecture .....	4
3.1.1	GPS Receiver, Pre-Amplifier, and Antenna .....	4
3.1.2	RF Data Link .....	4
3.2.3	Notebook Computer (386/7) .....	6
3.2.4	Battery Power Supply Unit .....	6
3.2.5	GS Interfaces .....	6
3.2	Airborne Sub-System (AS) Architecture .....	6
3.2.1	GPS Receiver, Pre-Amplifier, and Antenna .....	8
3.2.2	RF Data Link .....	8
3.2.3	Notebook Computer (486DX) .....	8
3.2.4	I/O Processor (186) .....	8
3.2.5	HSI Interface and DATAC Terminal Interface Processor (8751) .....	8
3.2.6	Battery Power Supply Unit .....	9
3.2.7	AS Interfaces .....	9
4.	UPLINK MESSAGE FORMAT .....	9
4.1	Research Message Format .....	9
4.2	TSRV Message Format .....	11
5.	SOFTWARE .....	12
5.1	GS Module .....	12
5.2	AS Module .....	12
5.3	Real Time Simulator Module .....	13
5.4	Data Reduction Module .....	13
6.0	BIBLIOGRAPHY .....	13

## **1. SUMMARY**

This semi-annual progress report provides an overview of the work performed during the first six months of Grant NAG 1 1423, titled "GPS Interferometry." The Global Positioning System (GPS) is a satellite-based positioning and timing system. Through the use of interferometric processing techniques, it is feasible to obtain sub-decimeter position accuracies for an aircraft in flight. The proposed duration of this Grant is three years. During the first year of the Grant, the efforts are focussed on two topics:

- Continued development of GPS Interferometry core technology;
- Rapid technology demonstration of GPS interferometry through the design and implementation of a flight reference/autoland system.

Multipath error has been the emphasis of the continued development of GPS Interferometry core technology. The results have been documented in a Doctoral Dissertation (ref. 1) and a conference paper (ref. 2).

The design and implementation of the flight reference/autoland system is nearing completion. The remainder of this progress report summarizes the architecture of this system.

## **2. INTRODUCTION**

The goal of the flight reference/autoland system is to achieve real time, three-dimensional relative positioning accuracies better than 0.1 meter. The system consists of a ground sub-system (GS) and an airborne sub-system (AS). The GS uses a carrier phase tracking GPS receiver, a processor, and a VHF or UHF data link to broadcast raw measurement data, including pseudorange and carrier phase measurements, at a rate of once per second. The AS also uses a carrier phase tracking GPS receiver, a VHF data link and a processor which performs all processing of the interferometric measurement data. The data renewal rate of the AS depends on the GPS receiver used, but will be at least twice per second. The system will initially be used as a flight reference system. Next, the real time outputs of the AS will be made available to the aircraft flight control system for precision guidance. This will result in a further proof of concept of the flight reference system and will also serve as an initial feasibility determination of the use of GPS interferometry for autoland and accurate surface positioning operations.

After the completion of the initial system, ground and flight testing will be performed at Ohio University using a Piper Saratoga (PA-32) research aircraft. Next, the system will be installed on NASA Langley's Transport Systems Research Vehicle (TSRV), which is a Boeing 737-100.

### **3. SYSTEM ARCHITECTURE**

The system consists of a ground sub-system (GS) and an airborne sub-system (AS). System performance strongly depends on the type of GPS receiver used in the GS and AS. To achieve the 0.1 meter accuracy goal, carrier phase tracking GPS receivers are required. Currently, the Ashtech P12 has been selected for this system. The P12 is a 12-channel receiver which tracks the C/A-Code on L1 and the P-Code on both L1 and L2. Raw and processed measurement data are output twice per second. For research purposes, Ashtech has agreed to make these receivers available on request at no cost to Ohio University. Once the system is installed on the TSRV, it is anticipated that NASA Langley's Ashtech GPS receivers will be used.

#### **3.1 Ground Sub-System (GS) Architecture**

The GS is designed as a stand-alone system with no external power requirements. The GS consists of the following components, see also Figure 1:

1. Carrier phase tracking GPS receiver, pre-amplifier, and GPS antenna;
2. RF data link, consisting of a 2400 bps modem and a VHF transmitter (for research purposes a 9600 bps UHF modem is used);
3. Notebook computer (386SX with math co-processor, two serial ports, and 60 Mbyte hard drive);
4. Battery power supply unit with charger.

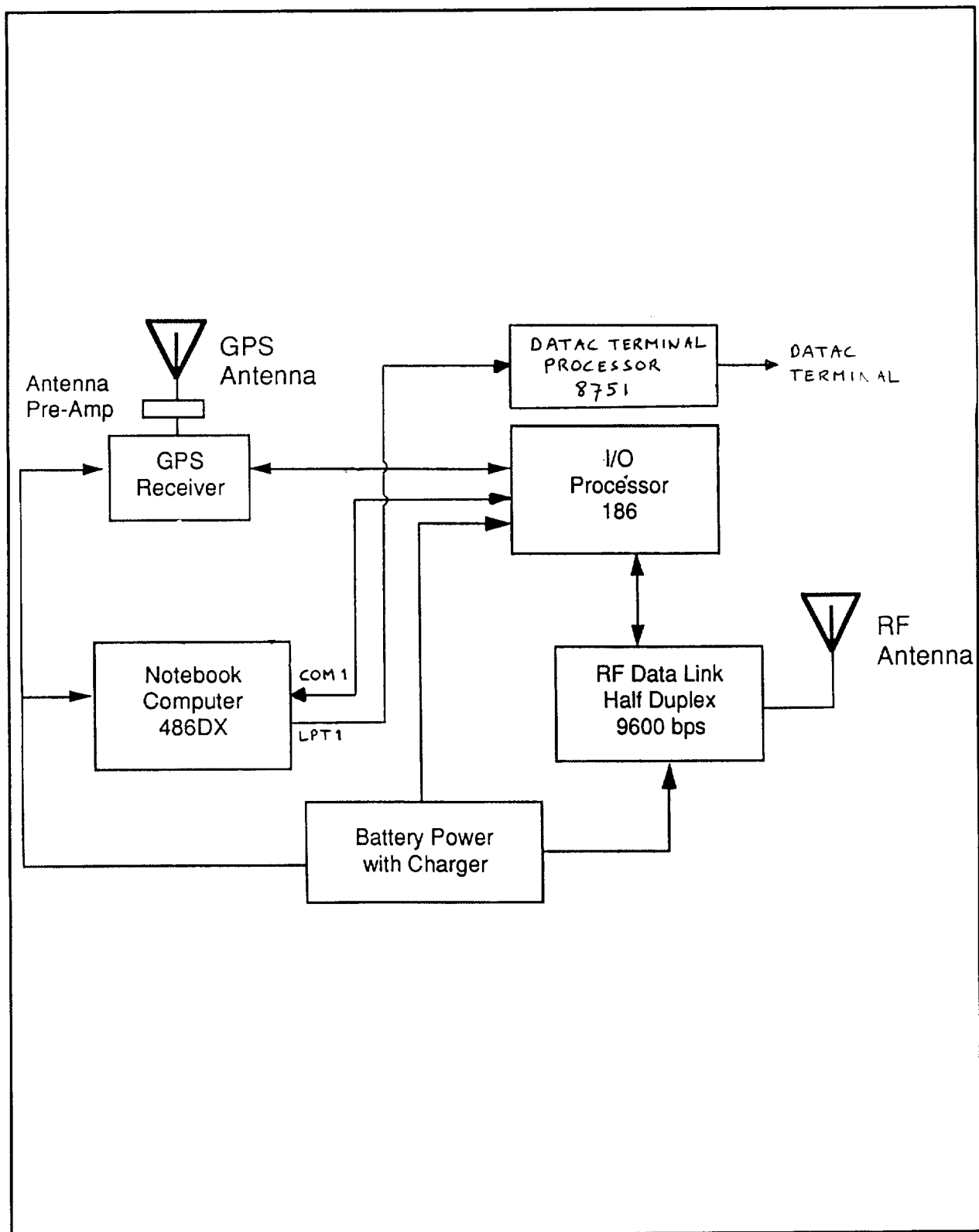
Preliminary flight tests at Ohio University will be based on this system architecture. Some modifications will be made for the flight tests on the TSRV, including the use of the TSRV data link. Each of the GS components are described in detail in the next four sections. This is followed by a section on the interfaces between the components.

##### **3.1.1 GPS Receiver, Pre-Amplifier, and Antenna**

The Ashtech P-12 GPS receiver was selected as the receiver for both the GS and the AS. The P-12 is a 12-channel carrier phase tracking receiver that is capable of tracking the C/A-Code on L1 and the P-Code on both L1 and L2. Although the P-Code will not be available to Standard Positioning System (SPS) users when GPS is declared operational by the DoD, several receiver manufacturers have receiver designs that will allow a SPS user to continue to track the GPS signals with P-Code tracking accuracies.

##### **3.1.2 RF Data Link**

Two types of data links can be used for interferometric GPS system. The first data link system has been developed by Ohio University for general use and consists of a 2400 bits per second (bps) modem utilizing Quadrature Phase Shift Keying (QPSK). The modem directly connects to a Very High Frequency (VHF) voice transmitter microphone input.



**Figure 1 Ground Sub-System (GS) Block Diagram.**

The digital data is transmitted to the modem using a RS-232 protocol. The modem is intended to operate in the broadcast mode, without the need for the continued transmission of synchronization data.

The second data link system is a commercially available 9600 bps modem/transmitter system operating in the Ultra High Frequency (UHF) band (DATARADIO T-Modem 96). This data link uses a 2-Watt transmitter and has an effective range of approximate 20 miles. The digital data is also transmitted to the modem using a RS-232 protocol. This data link is preferred over the 2400 bps link; however, a frequency assignment has not yet been obtained from the Federal Communications Commission (FCC).

### **3.2.3 Notebook Computer (386/7)**

A notebook computer was selected for the GS because of the power requirements. The main selection criteria was the availability of two serial communication ports to interface simultaneously with the GPS receiver and the data link. The ULTRA 386SX was purchased because of its relative low cost.

### **3.2.4 Battery Power Supply Unit**

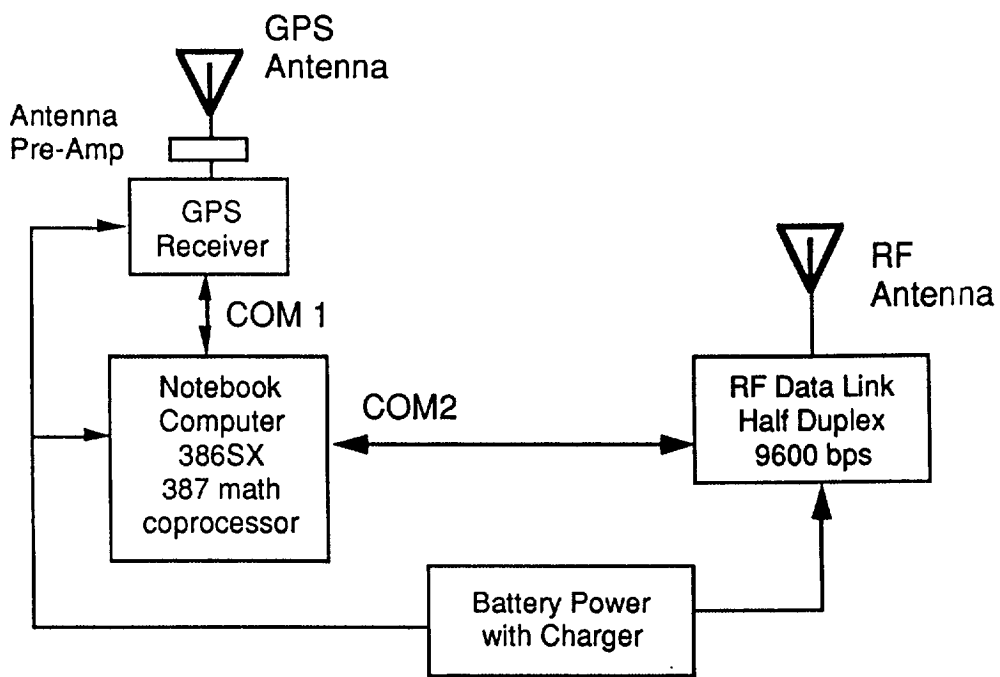
The battery power supply unit consists of two 12-Volt, 15 Amp-hour rechargeable batteries. The batteries are connected in parallel and provide for over 10 hours of uninterrupted operation of the GS.

### **3.2.5 GS Interfaces**

The GS interfaces are summarized in the following table.

Item	Element A	Element B	Interface
1	GPS Antenna	Low-Noise Amplifier (LNA)	Coax cable, TNC connector (p) on antenna and sma connector (p) on LNA
2	LNA	GPS receiver	Coax cable, sma connector (p) on LNA and N-type connector (p) on GPS
3	GPS receiver	Notebook computer (PC)	RS-232, serial port 1 on PC
4	PC	Datalink	RS-232, serial port 2 on PC

## **3.2 Airborne Sub-System (AS) Architecture**



**Figure 2 Air Sub-System (AS) Block Diagram.**

The AS is designed as a stand-alone system with no external power requirements. The AS consists of the following components, see also Figure 2:

1. Carrier phase tracking GPS receiver, pre-amplifier, and GPS antenna;
2. RF data link, consisting of a 2400 bps VHF modem or a 9600 bps UHF modem and receiver;
3. Notebook computer (486DX, one serial port, and 120 Mbyte hard drive);
4. I/O processor (186);
5. HSI interface or DATAC Terminal interface processor (8751);
6. Battery power supply unit with charger.

Each of the AS components are described in detail in the next six sections. This is followed by a section on the interfaces between the components and the aircraft flight control system.

### **3.2.1 GPS Receiver, Pre-Amplifier, and Antenna**

See section 3.1.1.

### **3.2.2 RF Data Link**

See section 3.1.2.

### **3.2.3 Notebook Computer (486DX)**

A notebook computer was selected because of the power requirements. It was decided to require one serial port and one parallel port. An interface processor will be used to handle all Input/Output (I/O) operations. The Compudyne 486DX was selected because of its availability.

### **3.2.4 I/O Processor (186)**

The I/O processor is responsible for providing the interface between the Notebook computer; and the GPS receiver and the data link. An off-the-shelf Intel 80186-based processor card from RLC Enterprises, Inc. was selected because of previous experience with this particular device.

### **3.2.5 HSI Interface and DATAC Terminal Interface Processor (8751)**

Two types of interfaces are required for the system. During the initial flight testing, an interface is required to the Horizontal Situation Indicator (HSI) onboard the Piper Saratoga Research Aircraft. This interface has been developed by Ohio University for previous projects. A second interface is required when the system is installed on the

TSRV. This interface would accept the parallel data from the notebook computer and transmit it to a DATAC terminal. The design of this interface has been initiated.

### 3.2.6 Battery Power Supply Unit

The battery power supply unit consists of one 12-Volt, 15 Amp-hour rechargeable batteries. The battery provides for over 6 hours of uninterrupted operation of the AS. Note that an external power supply will be used when the system is installed on the TSRV.

### 3.2.7 AS Interfaces

The AS interfaces are summarized in the following table.

Item	Element A	Element B	Interface
1	GPS Antenna	Low-Noise Amplifier (LNA)	Coax cable, TNC connector (p) on antenna and sma connector (p) on LNA
2	LNA	GPS receiver	Coax cable, sma connector (p) on LNA and N-type connector (p) on GPS
3	GPS receiver	I/O Processor	RS-232
4	Datalink	I/O Processor	RS-232
5	Notebook Computer (PC)	I/O Processor	RS-232
6	PC	DATAC Terminal	63-pin connector

## 4. UPLINK MESSAGE FORMAT

Two message formats are considered:

- 1) Research message format which requires a 9600 bps data link. This message format allows for the transmission of measurement data (C/A-L1, P-L1, P-L2) for up to eleven satellites;
- 2) TSRV message format which requires a 2400 bps data link. This format uses only one type of measurement data.

#### 4.1 Research Message Format

The research message format allows for three message types:

1. Reference data
2. Ephemeris data
3. Raw measurement data

##### Message Type 1: Reference Data Message Format

Contents	Units	Bytes
Synchronization Characters	none	2
Message Type (= 1)	none	1
Time (GPS time of week)	seconds	8
Ref. antenna x-coordinate (ECEF)	m	8
Ref. antenna y-coordinate (ECEF)	m	8
Ref. antenna z-coordinate (ECEF)	m	8
Runway ref. x-coordinate (ECEF)	m	8
Runway ref. y-coordinate (ECEF)	m	8
Runway ref. z-coordinate (ECEF)	m	8
Runway heading (true geodetic)	degrees	8
Magnetic variation	degrees	8
Check sum	none	2
		-----
Total		77 bytes

##### Message Type 2: Ephemeris Data Message Format

Contents	Units	Bytes
Synchronization Characters	none	2
Message Type (= 2)	none	1
Ephemeris in Ashtech format (delete 11 byte header and <CR><LF>)		132
Check sum	none	2
		-----
Total		137 per satellite

### Message Type 3: Raw Measurement Data Message Format

Contents	Units	Bytes
Synchronization Characters	none	2
Message Type (= 3)	none	1
Time of measurement (GPS tow)	seconds	8
Number of satellites (up to 11)	none	1
Up to 11 times the following structure		
SVID	none	1
SNR	dB-Hz	1
Full carrier phase C/A-L1	cycles	8
Full carrier phase P-L1	cycles	8
Full carrier phase P-L2	cycles	8
Pseudorange CA-L1	m	8
Pseudorange P-L1	m	8
Pseudorange P-L2	m	8
Doppler CA-L1	Hz	4
Doppler P-L1	Hz	4
Doppler P-L2	Hz	4
Check sum	none	2
		-----
Total		14 + nx62

The above message types lead to the following research requirement:

Messages sent once per second:

Message Type 1 (one message)	77 bytes
Message Type 2 (one message)	137 bytes
Message Type 3 (14+13*62)	696 bytes
	-----
Total	910 bytes

Each byte consists of one start bit, eight data bits, and one stop bit, resulting in a required bit rate of 9100 bits per second.

#### 4.2 TSRV Message Format

The TSRV message format is designed to operate with the 2400 bps packet radio link. For this case, only the raw measurement data message type is used. The format is as follows.

#### Message type 4: TSRV Raw Measurement Data Message Format

Contents	Units	Bytes
Synchronization Characters (\$U)	none	2
Message Type (= 4)	none	1
Time of measurement (GPS tow)	seconds	8
Eight times the following structure		
SVID	none	1
Pseudorange	m	8
Full carrier phase	cycles	8
Check sum	none	2
Carriage Return & Line Feed	none	2
		-----
Total		151

Because the TSRV data link adds several identification characters, the full 240 bytes per second are not available for raw data. The pseudorange can either be the C/A-Code pseudorange of the P1-P2 narrow-lane pseudorange. Similarly, the carrier phase can either be the C/A-Code carrier phase or the P1-P2 wide-lane carrier phase.

## 5. SOFTWARE

The software for the flight reference/autoland system is divided into four modules:

- 1) GS Module
- 2) AS Module
- 3) Real Time Simulator Module
- 4) Data Reduction Module

All software is written in FORTRAN77 or in assembly language if required. Both the AS and GS use interrupt driven routines for the serial port interfaces. The following sections provide an overview of the functional tasks performed by the software.

### 5.1 GS Module

The GS Module is responsible for the following tasks:

- 1) Program initialization
- 2) Program control
- 3) GPS receiver initialization
- 4) Datalink initialization
- 5) Data collection from GPS receiver

- 6) Decode ground GPS receiver data
- 7) Operator interface
- 8) Format data link messages
- 9) Transmit data link messages
- 10) Data format and storage to HD
- 11) Program termination

## **5.2 AS Module**

The AS Module is responsible for the following tasks:

- 1) Program initialization
- 2) Program control
- 3) GPS receiver initialization
- 4) Datalink initialization
- 5) I/O computer initialization
- 6) DATAC terminal I/O initialization
- 7) I/O computer interface and data collection
- 8) Decode airborne GPS receiver data
- 9) Decode uplink messages
- 10) Interferometric data processing
- 11) Send data to DATAC terminal
- 12) Operator interface
- 13) Data format and storage to HD
- 14) Program termination

The Interferometric data processing task is further detailed below:

- 1) Initialization
- 2) Kalman Filter for Double Differences
- 3) Floating Solution
- 4) Ambiguity Resolution
- 5) Kalman Filter for Navigation Solution

## **5.3 Real Time Simulator Module**

The real time simulator module is designed to allow for the processing of collected measurement data, which greatly accelerates the testing of the real time software for the GS and AS.

## **5.4 Data Reduction Module**

The data reduction module is required for off-line processing of ground and flight data. This includes software for the processing of laser tracking truth data.

## **6.0 BIBLIOGRAPHY**

1. Braasch, M. S., "On the Characterization of GPS Multipath in the Final Approach and Landing Environment," Doctoral Dissertation, Ohio University, Athens, Ohio, 1992.
2. Waid, J. D., "Ground Station Siting Considerations for DGPS", Proceedings of the Institute of Navigation National Technical Meeting, San Francisco, CA, January, 1993.